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DIAMOND ORDNANCE FUZE LABORATORIES

DOFL PROJECT 24720

WASHINGTON 25, D.C.

DOFL REPORT TR-473

May 1957

STUDY OF THE FEASIBILITY OF DEVELOPING A PROXIMITY FUZE FOR CHEMICAL CORPS MUNITIONS

ORDNANCE CORPS • • • DEPARTMENT OF THE ARMY

SECRET

ABSTRACT

A short study was made of possible methods of proximity fuzing two Chemical Corps munitions, a sphere and a Flettner rotor, to provide air-bursts of 5 to 15 feet. Various types of fuzing systems, including mechanical, electrostatic, radio, acoustic, and optical types, were investigated and evaluated. A comparison of the important characteristics of the various fuze types is made. The choice of the fuze type for a given application must result from a combined evaluation by the fuze and munition designers. (S)

1. INTRODUCTION

This study is an outgrowth of an informal meeting in January 1957 of Ft. Detrick personnel and DOFL representatives. As a result of a general discussion of the problem of fuzing the type of small munitions developed by Ft. Detrick, DOFL undertook a short study to determine the feasibility of proximity fuzing a series of weapons, including spherical and Flettner rotor munitions (Figures 1 and 2). Such munitions may have spin rates of 10,000 rpm (max) shortly after release, dropping to 3000 to 6000 rpm at target; and since the munitions are clustered, interaction problems may be encountered in radiating-type fuzes.

Examination of the fuzing specifications (Appendix A) shows that these munitions impose several requirements which; in general, have not been encountered in previous DOFL fuze projects. One requirement that is particularly stringent is that of size. The fuze must ultimately be capable of being packaged in a 3-cu-in. volume. (Initially, a volume of 5 cu in. will be accepted.) A second novel characteristic is the long (8 to 10 min) operating period. It would be difficult to provide the power required for a vacuum-tube fuze for 10-min operation with a thermal-type power supply of reasonable size. However, commercial mercury- or dry-cell batteries of usable sizes can provide the necessary power. The limited operating-temperature range (0°C to 55°C) makes the use of these cells feasible, particularly if the power supply may be inserted into the fuze shortly before the time of operation. In addition, this narrow operating-temperature range permits the use of simple, low-cost transistor circuitry. Another significant operating characteristic is that the fuze should provide a mean burst height of 10 ft, with 85 percent of the rounds bursting between 5 and 15 ft, and the remainder of the operable rounds bursting between 0 and 25 ft.

This report covers a brief appraisal of the various fields of proximity fuzing. Each type, whether apparently promising or not, is herein presented for possible consideration by the munition designer. In this study, primary emphasis was placed on fuzing for the spherical munition.

2. FUZING SYSTEMS

2.1 Radio Doppler Fuze

The most widely known type of proximity fuze is the radio-doppler fuze. This is an active fuze, emitting radio-frequency energy. When the radio-doppler fuze approaches a target, a fraction of the radiated energy is reflected by the target and returned to the fuze. The phase of the returning waves is such as to reinforce or oppose the waves being radiated, depending on the distance between the fuze and target. The reinforcements and cancellations alternate at an approximately constant audio frequency (Doppler) and with increasing amplitude. This audio frequency is determined by the frequency of the radiated signal and the velocity of the fuze with respect to the target. The alternating audio-frequency voltage is applied to the input of an amplifier. The amplifier output signal is used to trigger the firing circuit, which initiates the explosive train.

2.1.1 Circuitry

The most simple radio doppler fuze circuit that could meet the 10-ft burst-height requirement, would consist of an r-f oscillator, an amplifier, and a thyratron. Two basic types of circuitry are presently available for use in such a radio-doppler-type fuze. One type utilizes vacuum tubes, and the other uses transistors. Each type has inherent advantages and disadvantages. Therefore, both were considered in this study.

2.1.1.1 Vacuum-Tube Circuitry

During the period June 1952 to December 1954, DOFL carried on an investigation of a radio doppler fuze for a spherical munition* of a size comparable with that considered in this study. A fuze design was developed to provide burst heights in the range 2 to 8 ft. This design utilized a loop antenna, a vacuum-tube oscillator, amplifier

* DOFL Report PR-55-9, Fuze, VT, T779, Final Progress Report, Mar-Dec 1954.

and thyratron. Arming was to be spin actuated, and the power supply (probably of the thermal type) was to be barometrically initiated at about 12,000 ft. This fuze, the T779, is not suitable for use in the munitions considered in this study, because it occupied about 11 cu in. and provided an average burst height of only about 5 ft. At the present time, however, it appears reasonable to consider the possibility of designing a fuze of the vacuum-tube radio-doppler type, which would give the desired burst heights and at the same time be inclosed within the amount of space available.

Probably the most compact type of vacuum-tube radio-doppler fuze circuit construction presently possible is that of the T178E1 mortar-fuze amplifier and firing circuit. This subassembly, consisting of three tubes and a printed circuit, occupies a volume of about 3/4 cu in. (1 1/4 x 1 1/4 x 1/2 in.). If 1/2 cu in. is allowed for oscillator components, 3/4 cu in. for a safety and arming mechanism utilizing the T1027 impact fuze (Sect. 2.1.5), and 2 cu in. for a mercury-cell power supply (Sect. 2.1.4.1), a total fuze volume (excluding the antenna) of 4.0 cu in. is possible.

This indicates that it is realistic to consider a radio-doppler fuze using vacuum tubes in a volume approaching 3 cu in. However, this would require a maximum degree of miniaturization, which would be reflected in unusually high development and production costs.

2.1.1.2 Transistor Circuitry

A radio-doppler-type fuze can probably more readily be designed within the ultimate 3-cu-in. volume by using transistors, which are smaller in size and require less power for operation.

An example of the small volume required for transistorized items is a hearing aid, which recently became available, that can be worn completely in the ear. This unit weighs 1/2 oz, and occupies a space of 0.3 cu in., including input and output transducers. The three-transistor circuit of this unit provides 50-db gain, and operates for a period of about 40 hr from the self-contained battery. Another example of the small size of transistor circuits is a commercially available, four-transistor amplifier, which provides 75-db gain. This unit, without transducers or power supply, is contained in a cylinder 1/2 in. in diameter and 3/16 in. high, a volume of 0.037 cu in. Although these two commercial devices may not incorporate the temperature compensation that would be required in the fuze, they do illustrate the degree of miniaturization possible today in transistor equipment.

The major problem in designing a transistor, radio-doppler fuze would be in the design of a suitable oscillator-antenna system. Indications are that the transistor oscillator would perform best with a low-impedance-type antenna. The frequency of operation must thus be high enough to limit the radiation resistance to acceptable levels. For a loop antenna, a frequency of more than 200 mc seems indicated Transistors are now being developed, which can provide the necessary power output at the desired frequency.*

The balance of the fuze would be very compact. The size of the amplifier would be largely dictated by the coupling capacitors required to achieve the proper frequency response. The cost of the electronic package (excluding the oscillator) could be expected to be under fifteen dollars in production quantities, for operation under the limited temperature and vibration requirements of these munitions. The mercury-cell power supply could be contained within a volume of 0.5 cu in., and possibly within a volume of 0.16 cu in. (Sect 2.1.4.2). The safety and arming system for the transistor, radio-doppler fuze would be of the same size as that for the vacuum-tube radio-doppler fuze.

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*Bell Telephone Laboratories transistor type M2039 can deliver 50 milliwatts into a matched load at 200 mc, and would provide an adequate signal-to-noise ratio for the use contemplated. It is however, an expensive item in its present developmental stage. It is estimated that the cost of this transistor will be about nine dollars each in 1960 (based on anticipated military requirements). Another transistor for possible use as an r-f oscillator is the Philco SBDT, which can deliver 30 milliwatts at 100mc. A rough cost estimate of this item is about twenty dollars each by mid-1958. A similar Philco type, which might deliver 5 milliwatts at 100 mc, would probably cost under five dollars by mid-1958. This last type would probably still provide an adequate signal-to-noise ratio.

2.1.2 Antennas for Spherical Munition

2.1.2.1 Fixed Dipole

One type of antenna which might be suitable for use on the spherical munition is the fixed dipole shown in Figure 3. Although such an antenna would necessitate the use of projections, it is likely that these would not reduce the clusterability of the round. In addition, the two added end volumes would provide additional space for the fuze proper. (Figure 4 illustrates an arrangement in which a transistor electronic circuit is packaged in one ear and the power supply is in the other.) The protrusions may provide a fairly good antenna for a radio-doppler fuze operating at a moderately high (100 mc) frequency, and would thus be suitable for use with either vacuum-tube or transistor circuitry.

2.1.2.2 Loop Antenna

A second type of antenna, and probably the one most consistent with the stated specifications, is a loop antenna similar to that used in the T779 fuze. With this loop, adequate sensitivities (8 to 15 volts) were obtained at 225 to 250 mc, with a B supply of 90 v.

Work on the T779 fuze indicated that it would be highly desirable to eliminate the loss effects of the munition payload on the antenna (Appendix B). This can be done by allowing a gap of 1/4 to 1/2 in. between the loop and the payload. To do this, the loop can be situated above the spherical surface of the munition, which seems desirable, or flush with the surface over an empty slot. In the latter case, the payload volume would be considerably reduced. Consequently, the spacing between the loop and the payload would be a compromise between payload volume and fuze performance. One possible loop antenna position might be on top of the ridge between the halves of the munition (Figure 5).

2.1.2.3 Extending Dipole

A third antenna considered is a dipole, in which wire radiating elements are extended and stabilized by centrifugal force due to spin (Figure 6). This would probably be the best antenna, electrically, because it could be made several feet in length, and could thus present a reasonably low impedance. The principal difficulty with this type antenna would be that any appreciable flexing of the antenna structure could cause a signal (due to changes in radiation resistance) approximating in magnitude the target-approach signal. However, if the frequency of these induced signals is sufficiently removed from the doppler frequency, such signals can be discriminated against.

The antenna radiating elements project at an angle of 90° from the axis of rotation. This results in variation of the radiation pattern with respect to the target. This modulates the target-approach signal at twice the rate of rotation. Therefore, if a single dipole were used, and if the munition were spinning at a rate of 2000 rpm, the peaks of the radiation pattern would occur at a rate of 2000/60 x 2, or 66 per sec. If the r-f oscillator frequency were 200 mc, and the rate of target approach (vertical fall) were 200 fps, the doppler frequency would be about $2V/\lambda = 400/5 = 80$ cps. Thus, the beat-frequency cycle would occur during a vertical fall of $200/(80 - 66) = 14$ ft. Since the desired burst height is only about 10 ft, and since the beat-frequency distance should be kept small with respect to the burst height, these conditions could not be tolerated. A possible solution would involve using multiple antennas, to raise the rate of occurrence of radiation peaks, and lowering the r-f oscillator frequency as much as possible, to reduce the doppler frequency. It should be noted that this antenna is the only type considered which must have a rotating antenna pattern.

2.1.2.4 Hemispherical Antenna

A fourth antenna considered for possible use with the spherical munition is the hemispherical type, consisting of two hemispheres separated by a small insulating gap (Figure 7). This type antenna is energized across the centers of the parallel sections at or near the spin axis. Such an antenna would require that the missile be either metallic or plated plastic.

Two principal advantages of this type antenna are: 1) the payload is not in the radiation field and can not affect oscillator operation, and 2) the antenna is fairly efficient at a reasonably low level of parallel loading resistance. Calculations indicate that radiation efficiency increases with gap size, but, unfortunately, loading resistance increases also. Since the oscillator, especially the transistor type, operates better with a low-impedance load, there is a conflict between the effects of gap size.

Computations of the antenna characteristics yield the following values of parallel resistance, reactance and radiation efficiency:

Frequency, 200 mc	
1/8" gap	1/4" gap
R_p = 22.4K ohms	R_p = 30.6K ohms
X_p = -16 ohms	X_p = -31 ohms
Eff = 63%	Eff = 86%

For comparison, a calculation was made for a thin wire loop of a 170-mil radius and the same 4-in. diameter. The following values were obtained:

R_p = 122K ohms

X_p = +330 ohms

Eff = 91%

It can be seen that the lower parallel resistance of the hemispherical antenna is obtained at the expense of lower radiation efficiency than the air loop, unless the gap is made very wide. The particular hemispherical antenna configuration used would have to be a compromise.

2.1.3 Antenna for Fletter Rotor

The choice of a suitable antenna configuration for the Flettner rotor munition is much easier than that for the spherical munition. A suitable antenna for the Flettner rotor would seem to be a dipole type in which one end plate is driven against the rest of the munition, or in which the munition is split into two halves.

2.1.4 Power Supply

2.1.4.1 Power Supply for Vacuum-Tube Circuitry

A power supply for a proximity fuze employing vacuum-tube circuitry should deliver the following voltages and currents:

B Supply : 90 v at 10 ma

A Supply : 1.4 v at 400 ma

C Supply : 7.5 v at 1 ma

The thermal-type power supply can not be used in this application, since a very large heat source would be required to provide operation over the long flight times (8 to 10 min). Available types that could provide such operation are the liquid-reserve (Navy type) energizer, ordinary dry-cell batteries, and mercury-cell batteries.

The smallest liquid-reserve power supply available that would supply A, B, and C voltages is a cylinder of 1 1/2-in. diameter and 1-in. length, a volume of 1 3/4 cu in., excluding the mechanism to break the ampule. However, this power supply is designed for setback (gun firing) breakage of the ampule, as are most liquid-reserve power supplies. Another drawback of this type power supply for this applica-tion is, that to obtain even electrolyte distribution the missile axis of rotation and the central axis of the power supply must be coincident. This munition probably can not meet this requirement. Development of a special cell structure would be prohibitively expensive.

A second type of power supply to be considered would utilize the hearing-aid-type dry cell to provide B and C voltages and the mercury cell to provide A voltage. A no. 505 dry-cell battery (22 1/2 volt) can provide the necessary 10-ma B current for 10 min. This type unit would require 0.0307 cu in. per volt. Using this type battery for both the B and C supplies and a mercury cell for the A supply, the total power-supply volume would be:

B, C stack	3.0 cu in.
A cell	.41 cu in.*
Total	3.41 cu in.

A third type power supply would utilize mercury cells throughout. This type cell for 10-ma current drain would require 0.010 cu in. per

*Although a cell of this size would be operated in an overloaded condition, sufficient power could be obtained for the short period of fuze operation.

volt. Therefore, a mercury-cell power supply would require a volume of:

B, C stack	1.6 cu in.
A cell	.41 cu in.
Total	2.01 cu in.

Thus, the smallest power supplies that could be used for a vacuum-tube, radio-doppler fuze are the liquid-reserve and the mercury-cell types. The major drawbacks of the liquid-electrolyte type in this application are the need for spin concentricity and the difficulty of breaking the ampule without setback forces. The major drawback of the mercury-cell type is the relatively limited storage life of such cells. These cells may be stored for six months to a year or two under the proper conditions.

The power-supply requirements for vacuum-tube fuzes could be somewhat reduced by utilizing tubes with lower power capabilities, operating at lower voltages, using pulse instead of CW transmission. Although the type 565 battery is the smallest available commercial cell, it can provide the 10-ma B current. Thus, while reducing the B-current requirement would permit a smaller B cell, this would require that a new cell design be developed for this application.

2.1.4.2 Power Supply for Transistor Circuitry

The power supply required for a radio-doppler fuze utilizing transistor circuitry would be relatively simple. Mercury cells providing 10 ma occupy a volume of 0.016 cu in. per volt. Thus, a conservative supply of 30 volts would occupy a volume of less than 0.5 cu in. A supply of 10 volts in a volume of about 0.16 cu in. may be adequate for a transistor fuze.

2.1.5 Safety and Arming System

A safety and arming system could easily be provided for either the spherical munition or the Flettner rotor munition for all fuzing systems considered by utilizing the presently existing T1027 mechanical impact fuze. The basic change needed to convert this fuse to proximity as well as impact operation is the inclusion of an electric detonator, which on initiation would drive the fuze stab into the primer.

2.1.6 Interaction

Because the radio-doppler fuze is an active fuze radiating energy, interaction effects can be expected when the rounds are dispensed in large numbers from clusters. If a coverage of 35 square miles by approximately 2000 rounds is assumed (using a square pattern), the average distance between rounds at impact is about 700 ft. If it were possible to arm the fuzes half way to the ground, at an average distance of 350 ft apart (not including vertical separation), then the combination of 10-ft-burst-height sensitivity, vertical scattering, frequency scattering, amplifier sophistication, would indicate that while the interaction problem if formidable, it is not at all insurmountable.

2.1.7 Summary of Radio-Fuze Characteristics

The principal difficulties to be encountered in designing a radio-doppler-type proximity fuze for the proposed application would probably be in confining the fuze within the required volume and in providing a suitable power supply. However, the absence of shock and extreme vibration, coupled with the limited temperature range over which the unit must operate, make the design of such a fuze feasible because they allow the use of dry-cell or mercury-cell power supplies (providing it is possible to insert the power supply shortly before use).

Since more work has been done, and , consequently, more experience has been gained on vacuum-tube circuitry than on transistor circuitry, the design of a 5-cu-in.-volume fuze would probably be most quickly and most economically accomplished through the use of vacuum-tube circuitry and a mercury-cell power supply. However, the use of transistor circuitry would offer the best assurance of designing a fuze within the 3-cu-in. volume, since both circuitry and power supply would be smaller than in the vacuum-tube design. The design of transistor circuitry for this application would be more expeditiously accomplished than for most other munitions, due to the less stringent temperature and shock characteristics of the round. Considerable experience has already been gained on transistor circuitry, and any additional knowledge gained would have considerable carry-over value to other small munitions fuzing problems.

2.2 Mechanical Fusing

Mechanical fuzes in general have the advantages of being simple, inexpensive, small and reliable. As a result, considerable effort has been made to devise fuzing systems which are mechanical, but which will provide air burst. Three of these methods are evaluated in this study. These were the following: leader-actuated fuze, probe fuze, and bounce fuze.

2.2.1 Leader-Actuated Fuze

The leader-actuated fuze utilizes a small mass, which precedes the munition in flight by a distance corresponding to the desired burst height, and which is connected to the munition by some physical means, usually a wire. On impact, this small mass sends a firing signal to the munition, thereby producing an air burst. The ballistic characteristics of the components of this system must be carefully controlled for proper operation. This type fuzing scheme seems unsuited to the application considered, due to the small size and spin of the missile, and the cluster-type release, with the attendent possibility of tangling the connecting cables.

2.2.2 Probe Fuze

The probe fuze is similar to the leader-actuated fuze. The probe fuze uses an extended element to sense physical contact with the target. This sensing element is usually rigidly attached to the munition.

Short studies had previously been made of the possibility of using a probe fuze for a spherical munition of only 2-in. diameter. An approach investigated was the extension of two or four flexible probes of 2-ft length. Experiments indicated that flexible probes of a foot or two in length would not seriously affect the ballistic stability of the round, although the spin rate of the round would be decreased. Two methods appear useful in transmitting the firing signal from the probe to the explosive train. One involves the use of dual insulated wires for the probe, and the other involves charging the missile electrostatically, so that probe contact with the ground would apply voltage to the detonator. A major shortcoming of this type probe fuze for the present application is that it would be impossible to obtain burst heights in the range of 10 ft.

2.2.3 Bounce Fuze

A third type mechanical fuze considered for use with the spherical and Flettner rotor munitions is the bounce fuze. This type fuze provides air burst by projecting the munition back into the air after impact. Most bounce fuzes are time fuzes, the time being measured from the instant of ground impact. Thus, a low order of timing accuracy can be tolerated.

A possible bounce fuze arrangement for use with the present spherical munition hardware is shown in Figure 8. In this configuration the round is encased in a layer of sponge rubber and an outer case of plastic. A lead projectile is incorporated in a barrel mounted off center in the inner sphere, so that the sphere, tends to assume a resting position with the projectile in a position below the center of the round. The outer plastic case contains a counterweight, to provide stability in flight.

Operation of this round is as follows (Figure 9): Impact shatters the outer plastic case, and the sponge rubber pads bounce the round out of the case. The T1027 impact fuse in the round initiates a pyrotechnic delay. The unbalanced sphere orients itself with the projectile barrel pointing in a generally downward direction. After about 3 sec, the pyrotechnic delay ignites a propellant charge, which fires the lead projectile downward, causing the sphere to be projected into the air by the recoil. A second delay burns through shortly afterward, causing the munition to explode in the air. A pyrotechnic by pass can be provided which will insure a delayed ground burst in the event of failure of any portion of the bouncing mechanism.

With a munition weighing 1.8 lb, and a desired function height of 10 ft, a projectile of about 0.075 lb would be used. If this projectile were made from lead of 0.437-in. diameter, a length of 1.21 in. would be necessary. Although the operating portions of the bounce fuze for the spherical munition would be relatively small, the total volume required for both the fuze and the outer casings would be about 15 cu in.

The Flettner rotor presents a more difficult problem. One device (Figure 10) for use with the Flettner rotor is shown in various stages of operation in Figure 11. The operation is as follows: on impact, one end plate is blown off, releasing the erecting members, which orient the body of the round in a vertical position. The round is then projected into the air and exploded in a manner similar to that used with the spherical munition.

The bounce fuze would have the advantages of other types of mechanical fuzes, such as simplicity and low cost. The chief disadvantages of this system would be its unproven performance, and its large space requirements.

2.2.4 Summary of Mechanical Fuze Characteristics

Of the mechanical fuze types considered, the bounce fuze appears to be the most promising type for this application. Such a fuze would be relatively low in cost, compared with most other types of fuzing. However, there is considerable uncertainty as to the spread in burst heights for vari[illegible]s of impact conditions. In addition, present fuze designs require substantial amounts of space.

2.3 Electrostatic Fuzing

2.3.1 Theory of Operation

Electrostatic fuzing for a certain small munition has already been studied. The principle of operation of this type fuze is as follows: A munition is divided into two conducting segments by an insulating segment and charged to a high positive potential, about 20,000 v. (Such a charge is readily obtained by ejecting a suitable dust from the munition in flight, or by contact charging the missile from an external source.) As the positively charged munition approaches the ground, it induces a progressively increasing negative charge on the ground. The electrostatic field of the ground charge causes the potential of that segment that is closer to the ground to become more negative than the other segment, due to the redistribution of charge. The insulating segment is shunted by an electronic circuit, which detects the voltage change, and causes the munition to explode.

2.3.2 Fuze Design for Spherical Munition

The possibility of using an electrostatic fuze (ESF) for the spherical munition was investigated. In order that one segment of the sphere be closer to the ground than the other, it is necessary to divide the sphere horizontally. Thus, in the case of the spherical munition, there is a continuous redistribution of charge as the munition rotates in proximity to the ground. This produces an a-c signal of the rotational frequency. The distance the munition falls between signal peaks is

$$S = \frac{V \sin \theta}{f}$$ where: S = separation distance between peaks
V = glide velocity
θ = glide angle, and
F = spin frequency.

For a typical case:

$$S = \frac{160 \sin 60°}{4500/60} = 1.8 \text{ft.}$$

An ESF circuit that might be suitable for use in the spherical munition is shown in Figure 12. This circuit is a variation of a two-tube circuit which has yielded function heights up to 15 ft on the 81-mm mortar shell. All of the electronic components, plus a complete safety and arming system for this munition have been assembled in a volume of 2.8 cu in. The use of a transistor amplifier and firing circuit may further reduce this volume. The dust dispenser and power supply are not included in the 2.8-cu-in. volume. The dust dispenser may be inserted near the surface of the sphere, or might possibly be incorporated in the cluster itself. The power required is 2 v at about 80 ma, and 150 v at 10^{-6} amps. A mercury cell can deliver the former, and one of the low-current, solid-state batteries now being developed or a mercury-cell battery can deliver the latter.

The burst-height sensitivity of this fuze depends on the thyratron grid bias and on the magnitude of the input signal. The theoretical input signals for a 4 1/2-in. spherical munition were computed as follows:

Height (ft)	Signal (v)
10	0.5
5	2.3
2	17
1	80

The circuit of Fig 12 requires about 1 volt to fire. A simpler one-tube circuit can be made which will operate on a 5-v signal. The targets for which these signals were computed were assumed to be conductive. As the conductivity of the target decreases, the magnitude of the signal decreases, although the extent to which the function height is affected has not been determined. However, this decrease is limited by the polarization that occurs in all dielectrics. The availability of a signal with a dielectric has been demonstrated by laboratory tests using a Lucite target. Electrostatic fuzes have functioned properly over dry sand in field tests. The presence of moisture and other impurities in and on the ground will increase the conductivity, and hence the fuze input signal over that of a dielectric.

One drawback of the electrostatic fuze is that, in the past, its performance has deteriorated greatly in rain, probably to about 25 percent. Laboratory experiments have indicated, however, that it might be possible to achieve some degree of protection against premature functioning in rain by the use of a simple RC interstage integrating circuit.

2.3.3 Summary of Electrostatic Fuze Characteristics

The spherical munition may be electrostatically fuzed to provide burst heights up to about 5 ft. The 10-ft burst height, however, might require a sensitivity that would make the fuze unstable. The electrostatic fuze is simple, inexpensive, and has good countermeasures characteristics, but operability in the rain is questionable.

2.4 Acoustic Fuze

2.4.1 Description

The feasibility of an active acoustic fuze has been considered at DOFL, but development effort has been directed only toward a passive acoustic fuze for antiaircraft application. The following is therefore a theoretical evaluation of the performance that might be expected from an active acoustic fuze against an earth target.

The acoustic fuse would be functionally similar to a radio doppler fuze with a transmitter and a receiver. The transmitter would send out waves of acoustic energy at probably a supersonic frequency which would upon reflection from the earth be detected by the receiver. The receiver would discriminate between direct and reflected waves by utilizing the doppler shift of the latter due to the vertical component of the missile velocity.

For a 10-ft function height, the transmitter could be an aerodynamically powered whistle operating in the 30-to60 kc range. The doppler shift with vertical Mach number is $f_r/f_o = (1+M)/(1-M)$, where f_o = whistle source frequency, f_r = received reflected frequency, and M = missile vertical Mach number. The frequency shift for various Mach numbers is as follows:

M	0.2	0.4	0.6
f_r/f_o	1.5	2.3	4.0

To determine air absorption and ground reflections, it is necessary to know the whistle signal frequency in air, f_a, which is given by $f_a/f_o = 1/(1-M)$. Typical ratios are

M	0.2	0.4	0.6
f_a/f_o	1.25	1.67	2.5

The height d above a target at which a particular sound level must be emitted in order that it be reflected from the target and received at a height h can be determined from the following: $d/h = (1+M)/(1-M)$ -- the same ratio as f_r/f_o, above.

The loss of signal upon ground reflection depends on both the frequency and the nature of the terrain. The air wavelength of the sound source herein considered is about 1/4 in. and thus any natural terrain will appear very rough and the reflection will be diffused. It is estimated that a loss of 20 db may occur on reflection from grass- or snow-covered ground.

The self-noise associated with missile flight, both aerodynamic and from mechanical vibration, is very difficult to estimate. Its magnitude was prohibitive for previously tested subsonic missiles, at the lower frequencies used in earlier work. That for the present choice of frequency will be considered later.

To determine the permissible levels of operation of the fuze for the present application, let $M = 0.15$, $f_0 = 30$kc, and $h = 10$ ft. Then $f_r = 40.5$ Kc, $f_a = 35.4$ Kc, $d = 13.5$ft, and $d + h = 23.5$ ft total air travel of that sound received at 10 ft. Air attenuation for 35 kc is about 0.4 db/ft or 9.4 db for 23.5 ft of air travel. A 1-watt omnidirectional sound source provides a sound pressure level (SPL) at 5 in. of about 126 db relative to 0.0002 microbar. This is the direct path signal level at the fuze transducer. The reduction in reflected signal level relative to the direct signal at 10-ft height is $20 \log 23.5/(5/12) = 35$db. If the target is a perfect reflector and the required signal-to-noise ratio is 3 (9.5db), the discrimination between the direct whistle signal and the reflected signal at the transducer must be $9.5 + 35 + 9.4 = 53.9$ db. This discrimination is independent of whistle power and for the assumed conditions must be between frequencies differing by only about 30 percent. (This is the minimum discrimination since loss due to ground reflection has been neglected.) The reflected SPL at the transducer for the 1-watt whistle is $126 - 44.4$ db or about 82 db. Self-noise levels in the low audio range on the nose of bombs falling at $M = 0.4$ have been measured to be between 100 and 110 db, but this decreases with decreasing Mach number. Thus for the assumed case, the discrimination between direct and reflected signals must be at least 53.9 db at a frequency separation of about 30 percent, and the noise level at the transducer must be less than about 72 db, for a 3-to-1 signal-to-noise ratio.

A typical barium-titanate transducer at its natural frequency might have sensitivity of - 75 db re 1 volt/dyne/cm^2.. For a SPL of 82 db, the signal voltage would be about 450 μv. More sensitive microphones might be used, but generally these are more susceptible to mechanical vibration, which could present a serious problem.

The use of a directional transmitter or receiver or both could relieve the problem of discrimination between direct and reflected waves and increase the level of the returned signal. This would, however, increase the required volume. Increasing the whistle power output would also raise the level of the returned signal. It is estimated that interaction between 5-ft function-height fuzes using omnidirectional characteristics would be serious at a 50-ft separation, if their relative velocities or frequencies were such as to produce the required doppler frequency shift. For every 6 db of directivity of either transmitter or receiver, this distance would be halved. The problem is still more severe for the 10-ft height.

One large problem area lies in the design of a suitable whistle, which can be either air driven or powered from an internal source. The whistle must have appreciable power output, be quite stable in frequency, and be of narrow bandwidth. These three features could best be achieved by using a whistle driven from an internal power source. However, conversion from electrical power to acoustic is generally very inefficient and for this munition could easily be as low as 1 percent. Thus a power supply of 100 watts is indicated. Since the volume requirements for such a supply are clearly prohibitive, the whistle would probably have to be air driven.

A further difficulty lies in providing suitable directional characteristics for both the transmitter and the receiver, and sufficient isolation from each other in the available space.

2.4.2 Summary

There are many problem areas associated with acoustic fuzing this munition. Many of these require novel developments such as an adequate signal source. In addition there are areas in which little or no data exist; for example, noise originating from the rotating fluted surfaces or from rain impacts. Thus, extensive experimental and developmental effort would be required for a valid assessment of the acoustic fuze. Because alternate fuzing schemes are closer to acheivement and because a successful acoustic fuze program would provide an item which would have no unique advantages, this approach does not appear attractive at this time.

2.5 Optical Fuze

2.5.1 Description

Previous work at DOFL on optical fuzing has been restricted to two types of passive systems and one active system suitable for use only on large missiles. For the present application, an active system such as described below appears promising.

The unit would have a transmitter and receiver focused on a small area at the required function distance. Since the accuracy of this type of system would be proportional to the distance between the light source and receiver, an analysis was made of an arrangement in which the source and receiver were located in protuberances at opposite ends of the rotational axis of the missile, and fin-stabilised nonrotating shields were used around the source and receiver to decrease background illumination. This system is illustrated in Figure 13. The transmitting and receiving beam must maintain their alignment at all times and thus the two fins that direct the beams along the flight path will probably have to be tied together mechanically if they prove at all unstable.

A type 222 tungsten filament bulb with a built-in lens would be suitable as the light source. This requires 2.5 v at 0.25 amp. The receiver could well be a cadmium selenide photoconductive detector, since it is one of the most sensitive detectors available that has fast enough response for fuse use. This detector peaks in the infrared band but has sensitivity into the visible spectrum. The power supply could be either of the dry-cell or mercury-cell type. Two type 12R mercury cells will provide ample filament power for the required time, in a volume of about 0.6 cu in.

Calculations were made that indicate that a light detector output of about 1 mv will be obtained under the poorest conditions if a bias of about 30 v is used, with the detector working into a matched load. The bias-supply current drain would be exceedingly small and could be obtained from the 2.5-v supply by a transistor converter. Use would also be made of a transistor amplifier and firing circuit. The detector should be matched to its load for the operating ambient light condition. Reduced back-ground illumination causes increases in cell resistance and sensitivity; the mismatch caused by the first is essentially compensated for by the latter. Thus, the night-time signal turns out to be about the same.

The noise in the system will originate both in the random current flow in the detector and in microphonics of components in the detector area of the circuitry. The magnitude of these will probably be less than the 1-mv expected minimum signal which may provide an adequate signal-to-noise ratio. One laboratory measurement simulating daylight operating conditions gave an S/N figure of 6. Refined techniques should increase this factor.

Although a simple amplitude detector and amplifier may be adequate, it appears that it would be desirable to modulate the transmitted beam at a multiple of the rotational frequency. The receiver would then be tuned to this frequency and unmodulated light would be discriminated against, by the amplifier.

The following is a sample calculation based on the system just described. Assume a type 222 lens-tip bulb. The total radiant flux intercepted by the source lens is 0.032 watts, according to laboratory measurements. The flux density at the detector lens is $F_L = rP_s / \pi R^2 = (1.1)(0.032)/ \pi (305)^2 = 1.1 \times 10^{-8}$ w/cm^2, where r = diffuse reflectivity of the ground (≈ 0.1), P_s = beam power of lamp source, and R = target distance in cm. The signal flux at the surface of the detector due to source-emitted light is $F_s = F_L A_L/A_D = 11 \times 10^{-9} \times 2/.02 = 11 \times 10^{-6}$ lumens/cm^2, where A_L = area of detector lens (sq cm), A_D = surface area of detector (sq cm), and therefore A_L/A_D = optical gain of detector system.

The background flux density as seen by the detector is determined by the sunlight reflected by the ground and is $F_B = rP_B A_G A_L / 2.5 \pi R^2 A_D = 0.07$ lumens/cm^2, where P_B = illumination due to sun = 11 lumens/cm^2 and A_G = area of illuminated ground seen by the detector, which is the magnification squared, times the detector area = $M^2 A_D = (R/F.L.)^2 A_D$ F. L. being the focal length of the detector lens (in cm). The figure of 2.5 in the above equation is the spectral correction factor. This factor arises because the illumination measurements are made in the visible which is a narrow band centered on 0.55 microns, while the CdSe cell sensitivity is primarily in a narrow band centered on 0.75 microns. The solar intensity in the CdSe band is about .9 that in the visible, while the tungsten lamp intensity is more than twice that in the visible. The fractional change in flux density due to a target is thus $F_s / F_B = 11 \times 10^{-6} /.07 = .16 \times 10^{-3}$.

The signal voltage for a bias E of 30 v, assuming the change in cell resistance proportional to the change in illumination is, with $R_C = R_L$, $V_S = E \Delta R_C R_L/(R_C + R_L)^2 = E \Delta R_C/4R_C = (30 \times .16)/4 = 1.2$ mv, where R_C = cell resistance, and R_L = load resistance.

This calculation of fractional flux change assumed maximum normal daylight illumination. If the high-gain lens system using directional beams in conjunction with stabilized hoods is not used, the system becomes marginal due to high background illumination. However, if operation is restricted to the period between sunset and sunrise, a much simpler fuze can probably be used.

A similar arrangement is applicable to the Flettner rotor.

2.5.2 Summary

An active optical fuse for the spherical munition appears possible if projections on the surface of the sphere along the missile axis are permitted. The signal is adequate and the S/N ratio can probably be sufficiently improved through the use of special techniques such as electrical filtering and modulation of the source. Power requirements could be satisfied by a mercury cell pack. The use of transistor amplifier and firing circuitry would be necessary because of space requirements.

2.6 Semiactive Microwave Fuze

Cursory consideration was given to a semiactive microwave fuzing system. This system utilizes simple receivers in each small munition and a master transmitter in a separate unit. Operation of this system (diagram, Figure 14) is as follows: The microwave master transmitter, suspended from a parachute above the free-falling munitions, radiates pulses of such a length that at the desired height above ground, the small munitions receive the directly transmitted energy and the energy reflected from the ground simultaneously. The receivers mix the two signals and extract and amplify the resultant doppler-frequency signals.

Such a system would have several advantages. The receivers would be small and relatively low cost. When dropped with 2000 munitions, the cost of even two transmitters would be only about twenty cents per munition. There would be no problem of interaction between munitions.

This system would also have several shortcomings. Munition spin might induce an unwanted doppler signal. Antenna design would be very difficult. Performance might deteriorate over mountainous terrain, due to the necessity of line-of-sight transmission from the transmitter to the munitions.

2.7 Capacity Fuze

A capacity fuzing system was investigated, which detects target proximity by a change in capacity between two segments of the fuze. The system studied involved transmitting a signal from one probe to another, while providing very stable neutralization of the direct coupling. Target proximity would change the amount of signal transmitted due to a change in the coupling between probes.

Breadbroad models have been constructed using this technique, and have yielded very stable function heights of 1 to 3 ft in laboratory tests. This type fuze could be built within a small volume, and can provide very good protection against countermeasures. However, it would not be possible to obtain 10-ft burst heights, although, if burst heights of less than 3 ft were considered, this device would be worthy of attention.

3. DISCUSSION

In order to compare the relative merits of the various types of fuzes discussed, several of the important characteristics have been tabulated (Table 1). An attempt has been made to rate the various systems for each of these characteristics. The relative importance of these characteristics, however, must be established jointly by the munition and fuze designers.

Of the types of fuzes considered, the transistor radio fuze and the electrostatic fuze are the only types that can reasonably be expected to be constructed within the ultimate 3-cu-in. volume (excluding the radio antenna). However, other types could be designed within the interim 5-cu-in. volume.

The 10-ft mean burst height requirement, on which the data in the table are based, is an important factor in the relative standing of the different fuze types. For instance, if the desired burst height were 20 ft, only the radio types and possibly the mechanical type could be considered. On the other hand, if the burst height were to be 5 ft, the electrostatic fuze would be very highly rated in relation to the radio types, particularly if rain operation were not required. The function-height stability is also affected by the required burst height. For example, since the 10-ft burst height is at the upper limit possible with the electrostatic fuze, burst-height stability is only poor, although at a height of 5 ft, stability would be good. (Burst heights of the mechanical bounce fuze would scatter considerably in any case.)

Although the radio fuzes would probably have the least protection gainst interaction and countermeasures, it may well be that the countermeasures problem is of little significance when the tactical conditions of use are considered. The countermeasures resistance of the electrostatic fuze and especially of the mechanical fuzes is outstanding.

The effect of weather would be most serious on the electrostatic fuze since rain drops not only tend to remove the charge on the munition, but also can cause false firing signals. An effect common to all the fusing systems is the microphony due to the physical impact of rain drops. Extensive experience with radio fuzes using vacuum tubes, however, has resulted in techniques which make these fuzes essentially immune to weather. This problem should be even less severe with transistor fuzes.

With regard to unit cost in production, the least expensive fuze would probably be the mechanical type. The cost of developing a transistor radio fuze would be relatively high, due to the necessity of component development, although the results of this development would have significant carry-over value to other munition shapes. Development costs of the various types of fuzes would depend greatly on the degree to which all of the military characteristics must be met.

Table 1. Some Comparisons of the Various Fuze Types

	Approx Min Fuze Vol (cu in.)	Probability of Providing Desired Burst Height Range	Resistance to Inter-action and Jamming	Immunity to Weather Conditions	Unit Cost in Production (dollars)
Vacuum Tube Doppler	5	good	good	very good	15-30
Transistor Doppler	< 3	good	good	very good	15-45
Accustic	$\simeq 5$	poor	very good	poor	15-45
Optical	5	excellent	very good	fair	15-45
ESF	< 3	poor	very good	poor	10-25
Mechanical	5	very poor	excellent	very good	5-15

S E C R E T

Figure 1. Spherical Munition.

Figure 2. Flettner Rotor Munition.

Figure 3. Spherical Munition with Fixed Dipole Antenna.

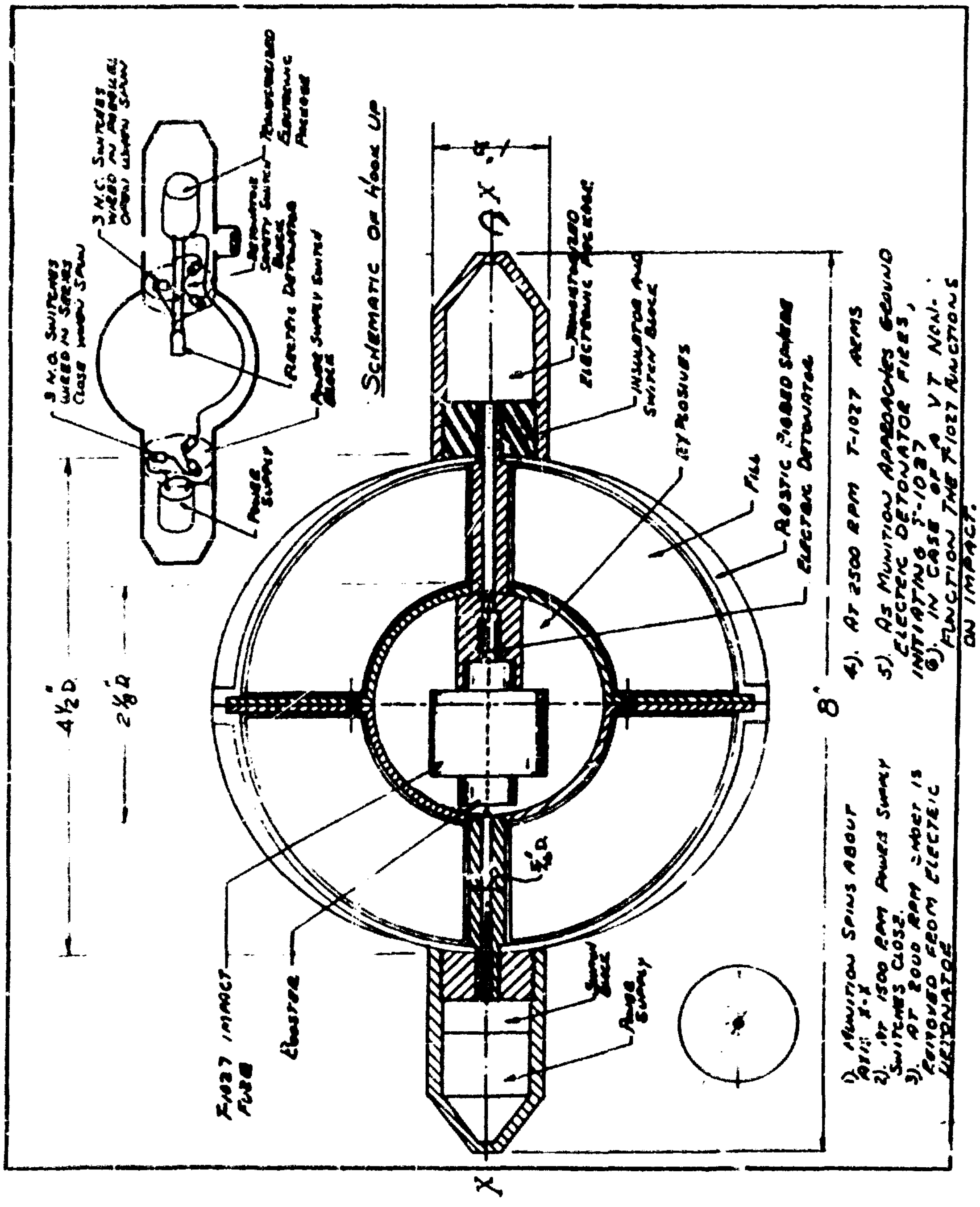

Figure 4. Layout of Transistor Radio Fuze with Fixed Dipole Antenna.

Figure 5. Loop Antenna for Spherical Munition.

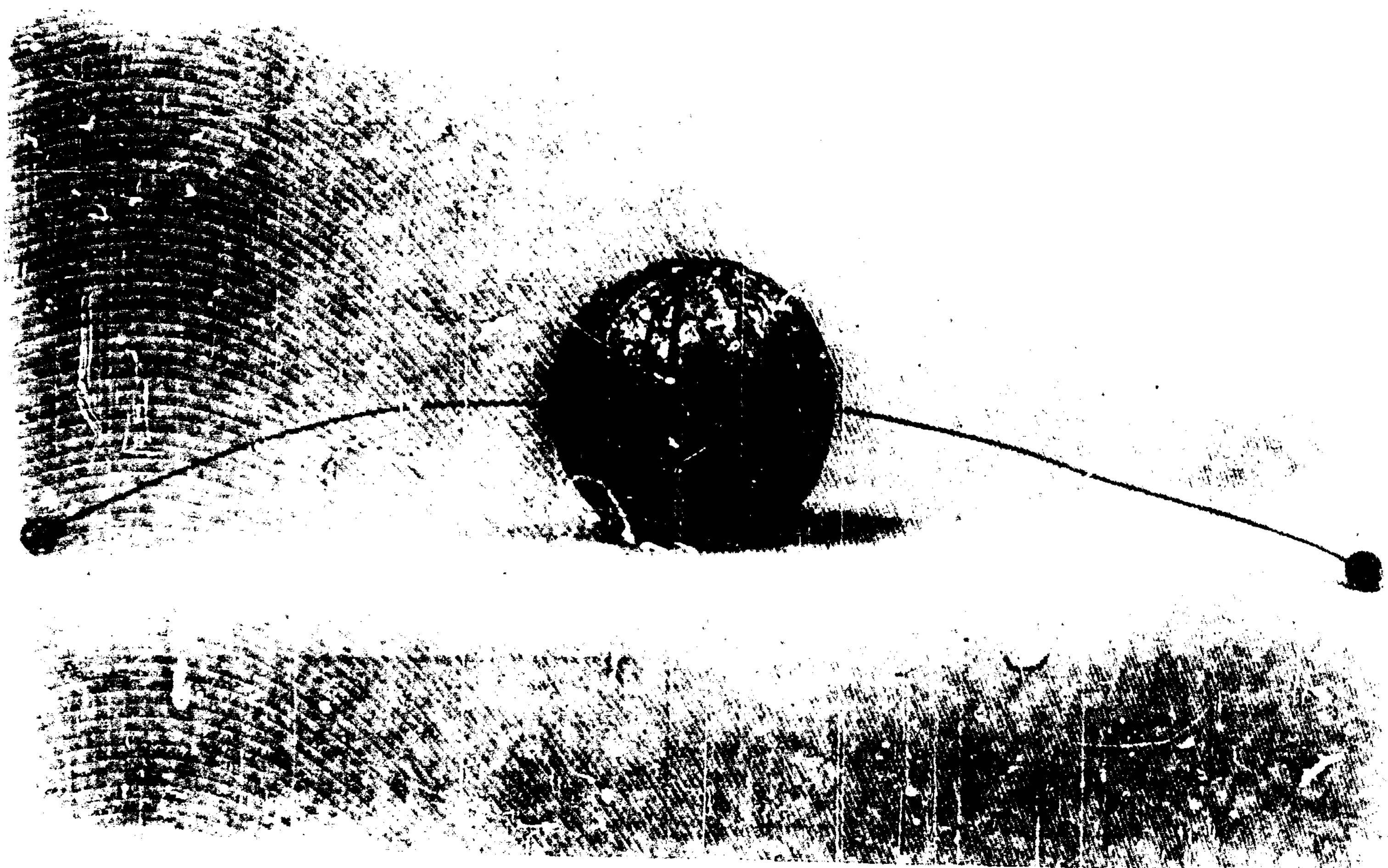

Figure 6. Extending Dipole Antenna for Spherical Munition.

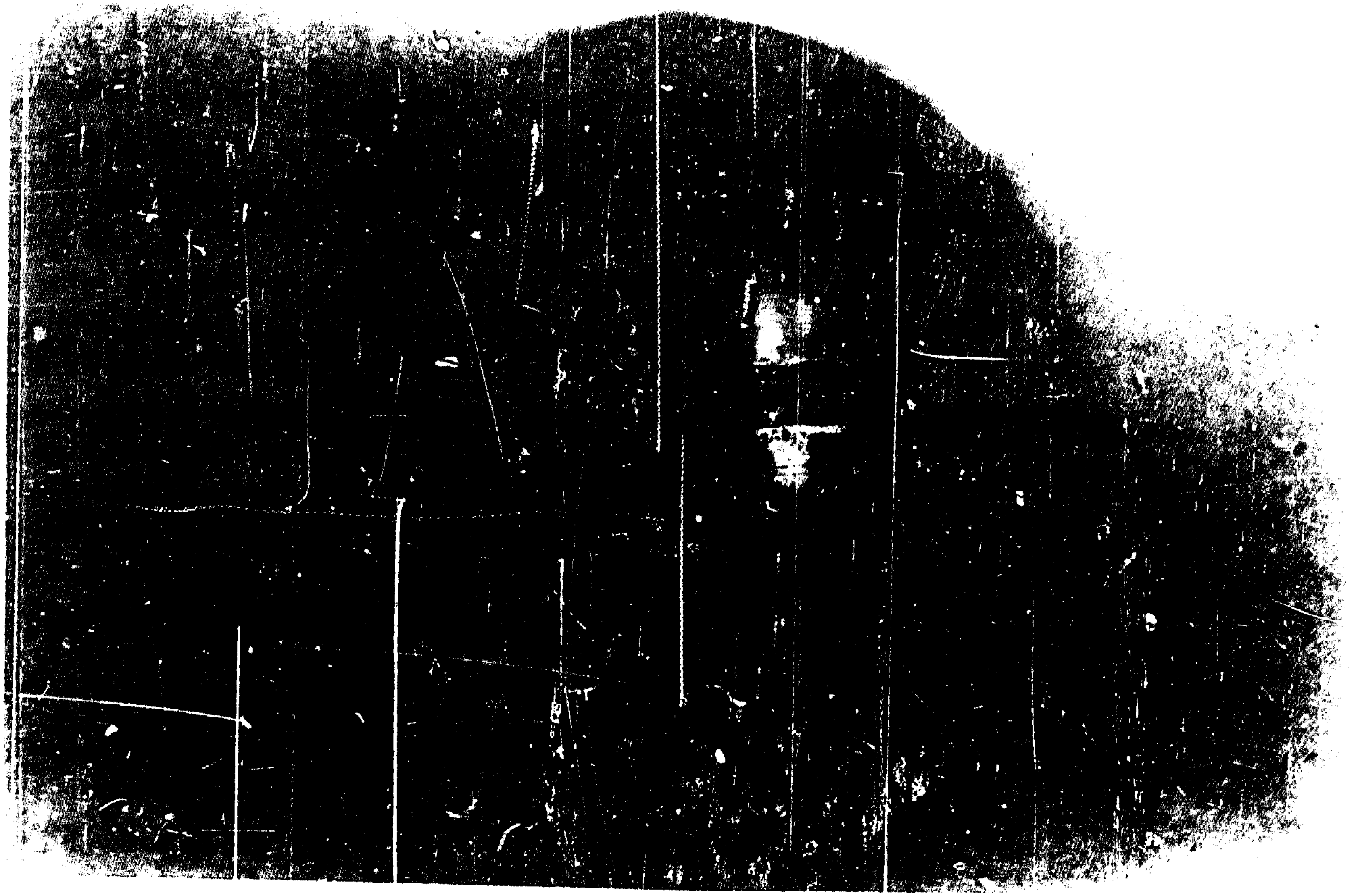

Figure 7. Hemispherical Antenna Mock-Up.

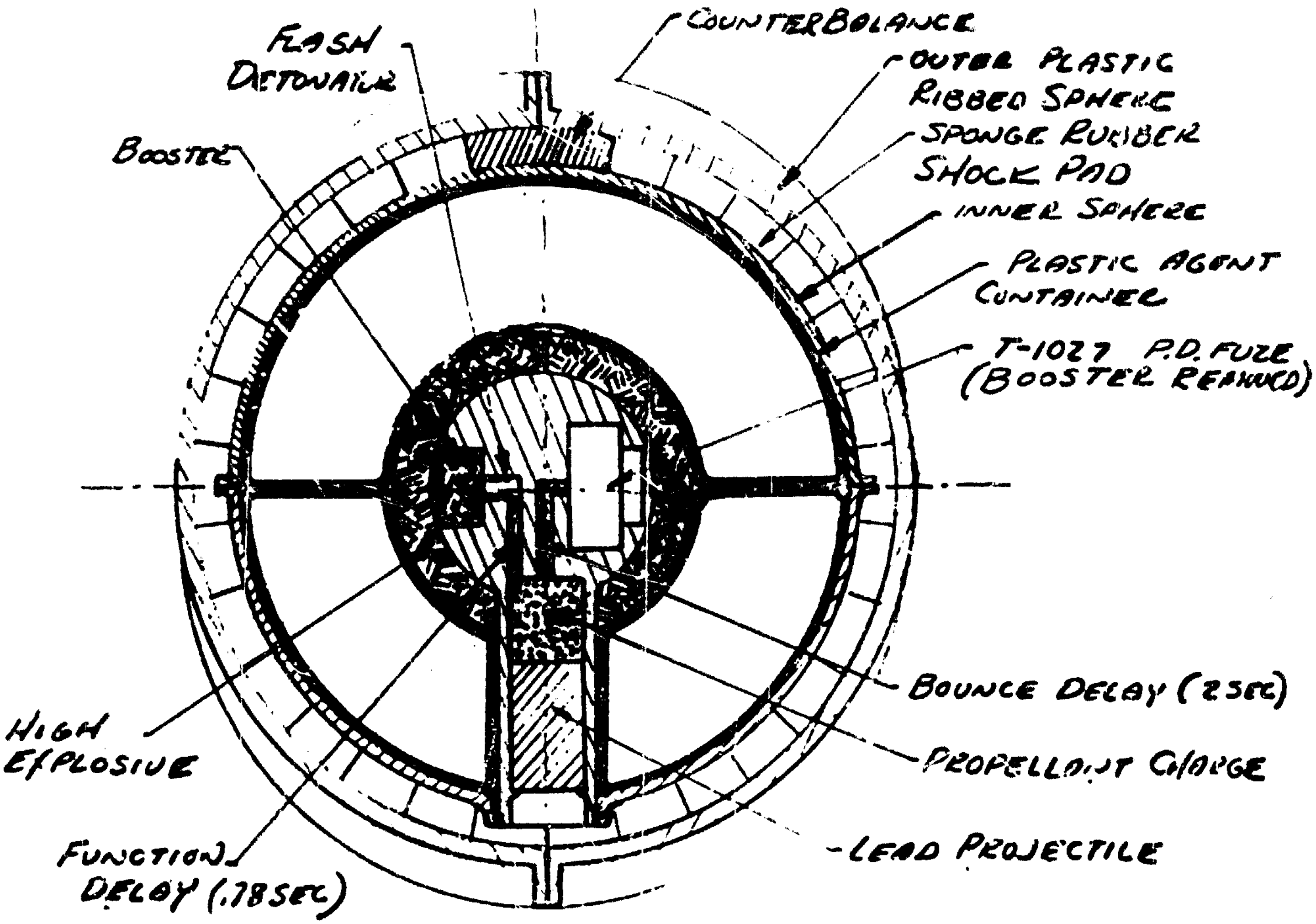

Figure 8. Proposed Bounce Round for 4 1/2 In. Diameter Ribbed Sphere.

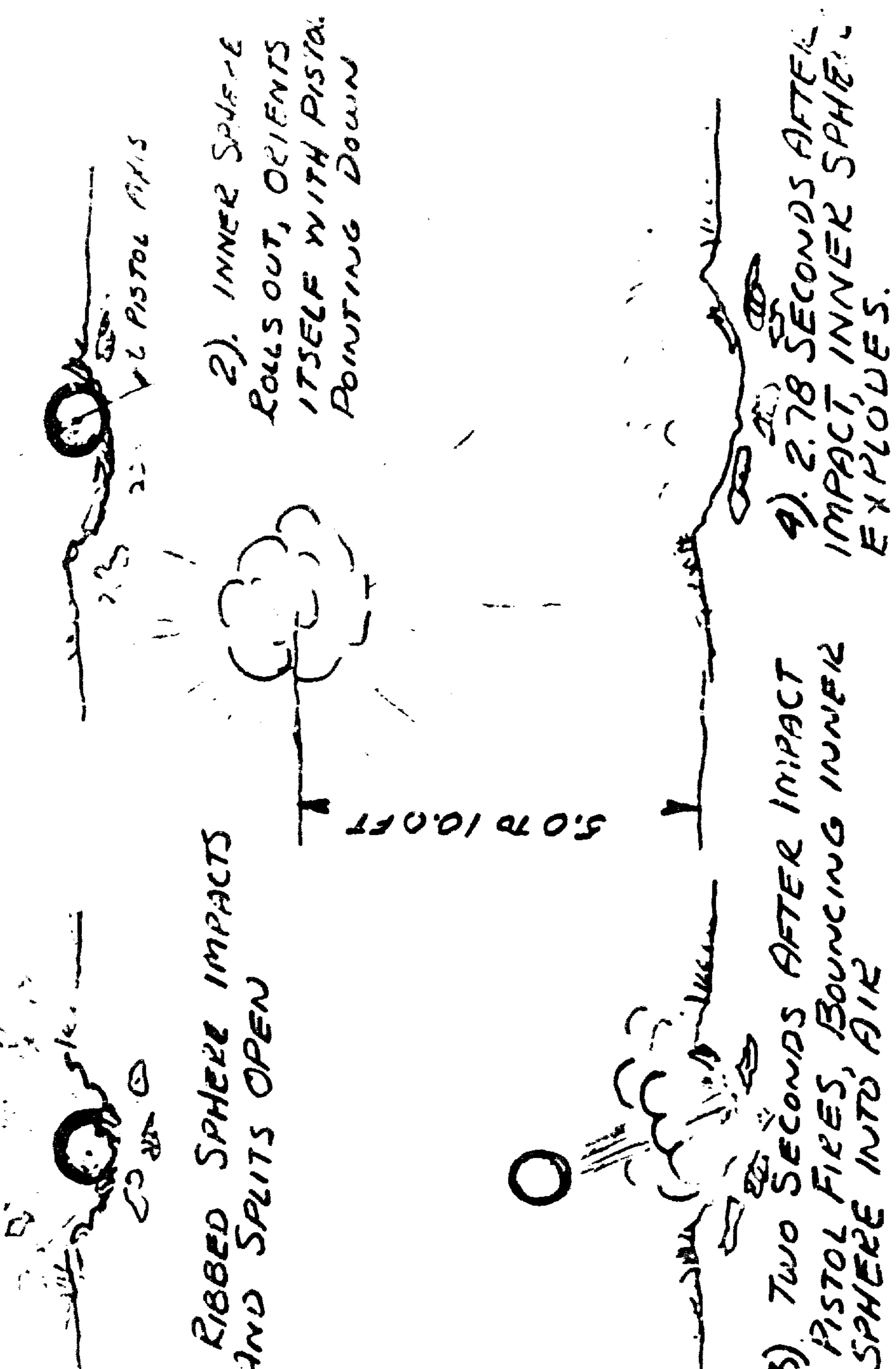

Figure 9. Function Sequence of Spherical Bounce Round.

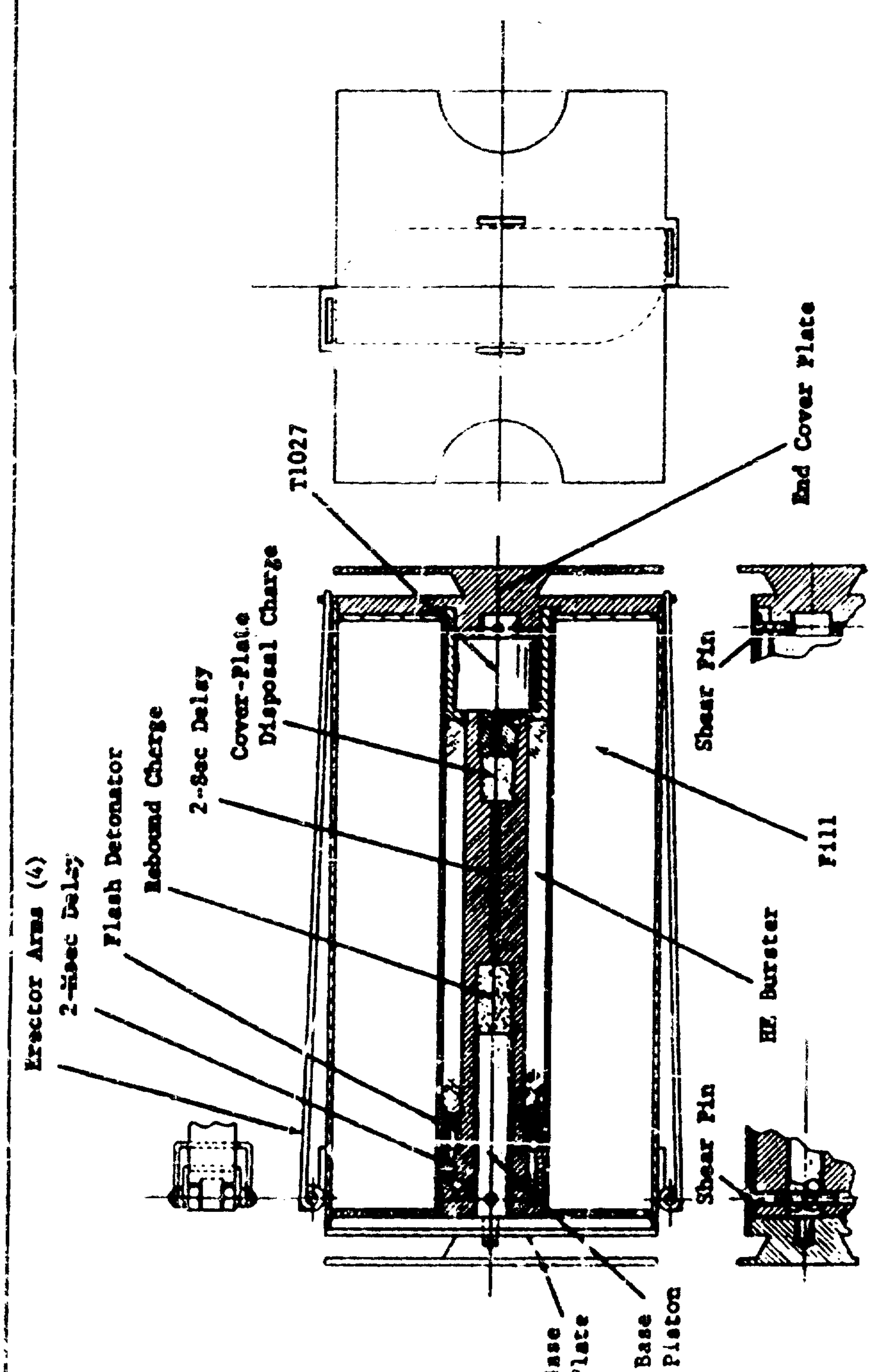

Figure 10. Bounce Fuze for Flettner Rotor.

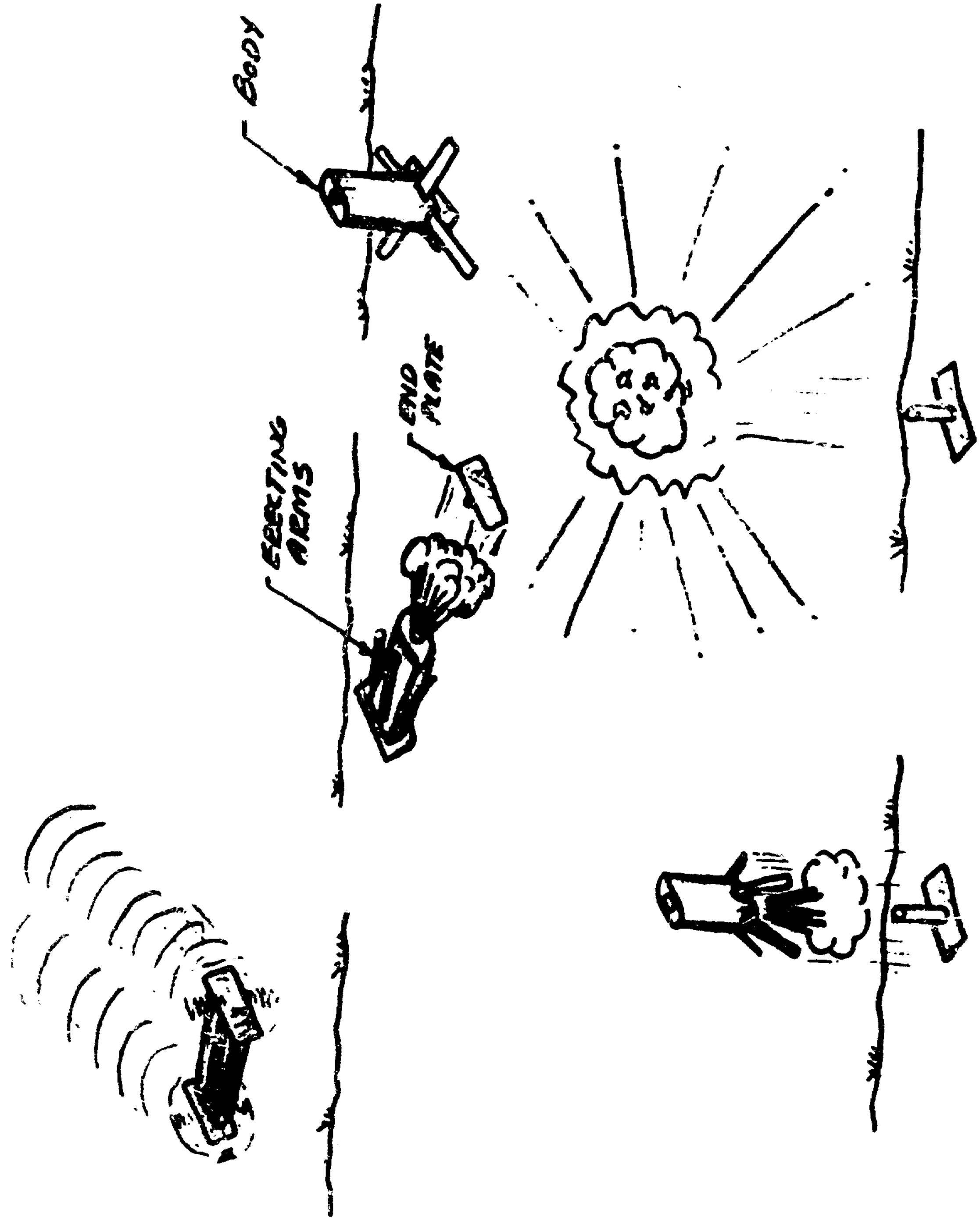

Figure 11. Function Sequence of Flettner Rotor Bounce Round.

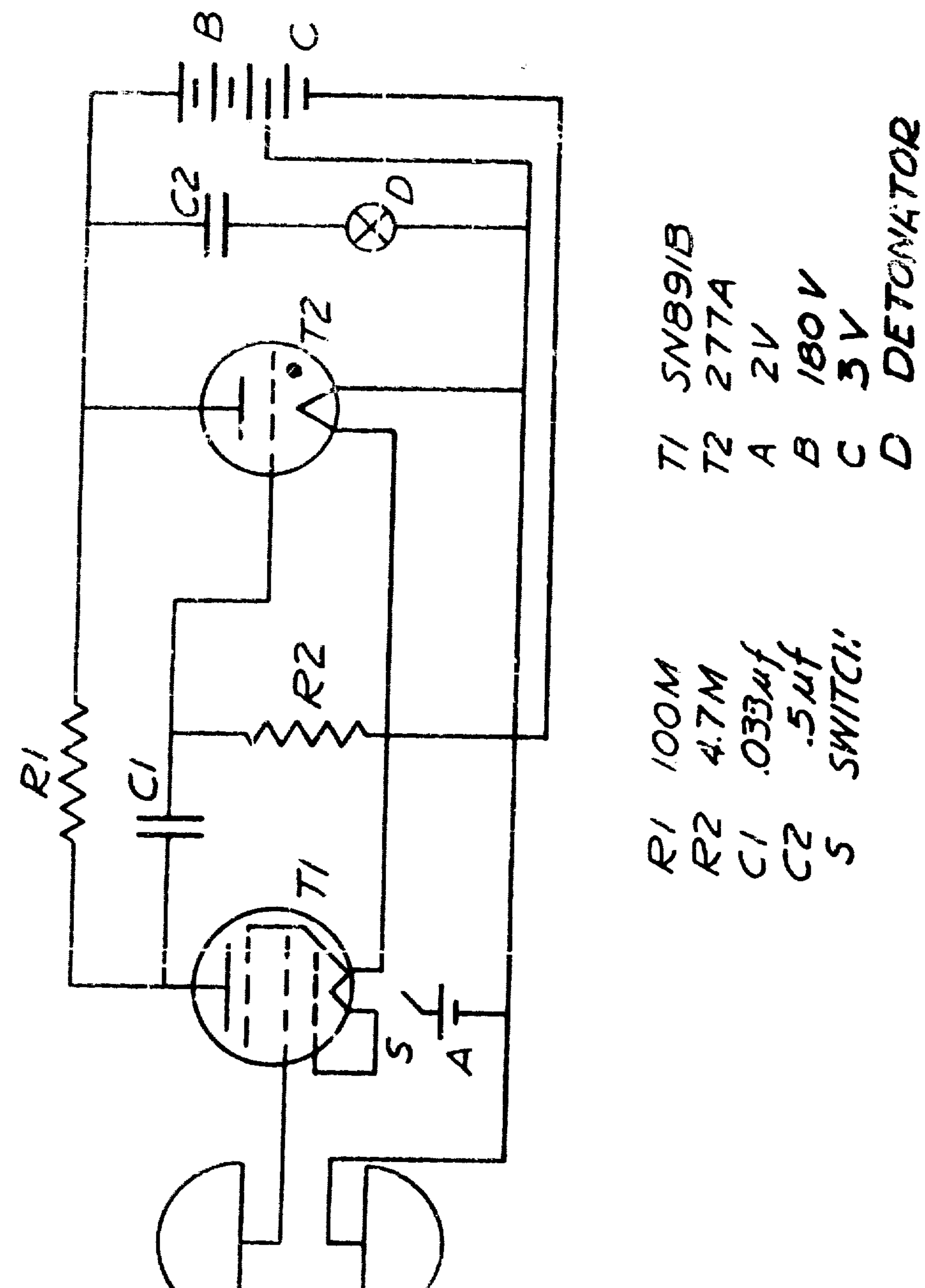

Figure 12. Electrostatic Fuze Circuit Diagram

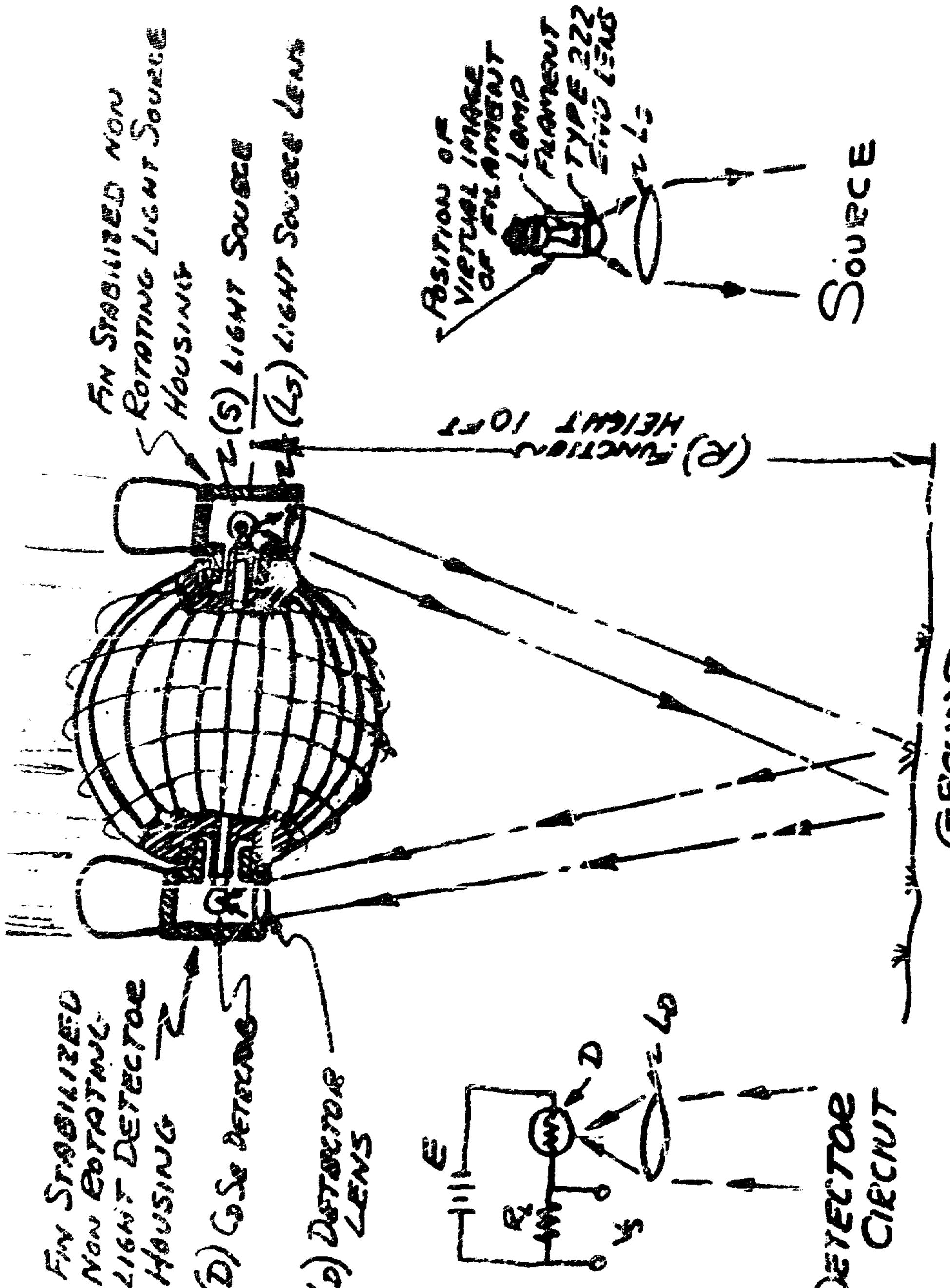

Figure 13. Optical Fuze, Operation.

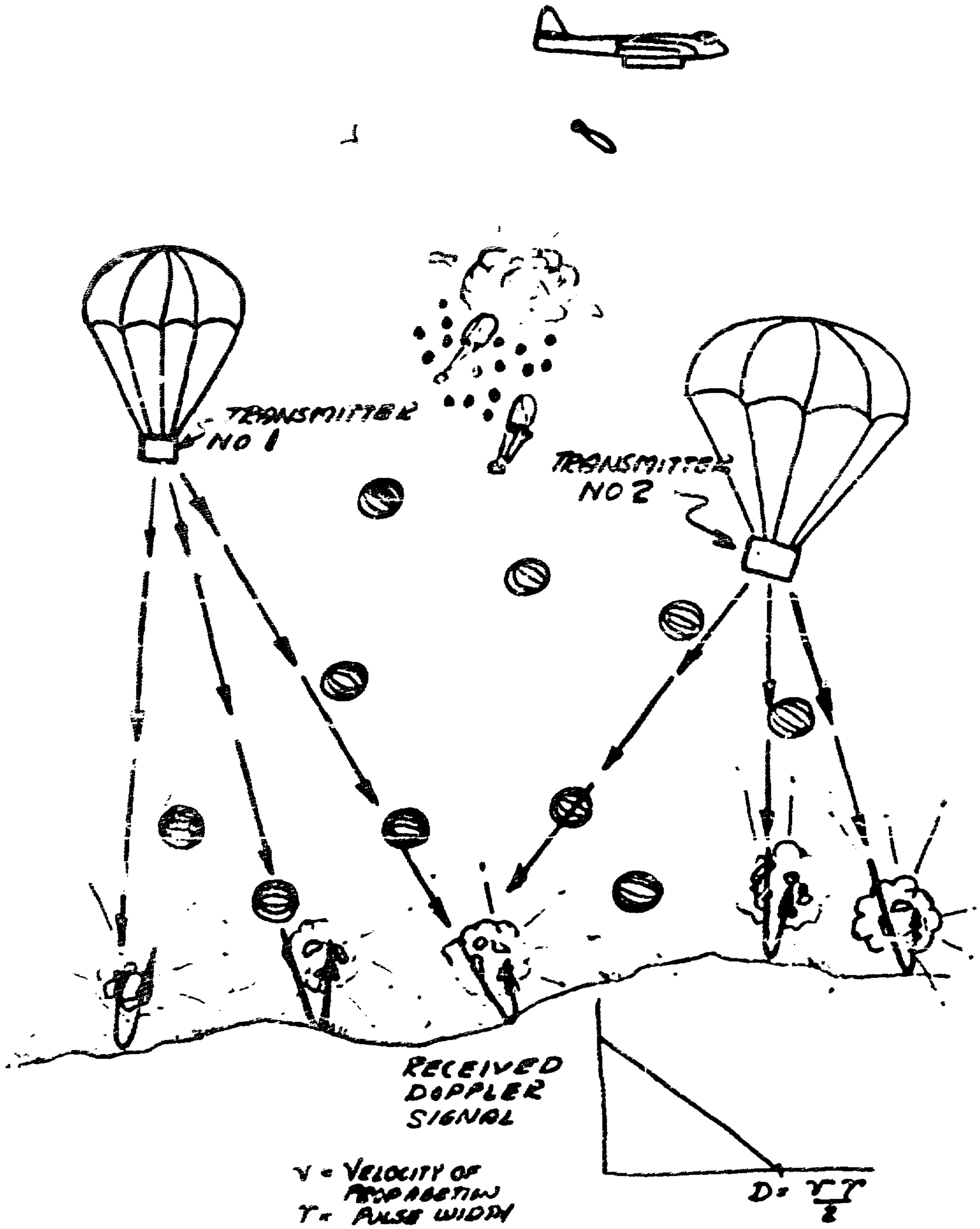

Figure 14. Microwave Fuze Action.

APPENDIX A

FUZING SPECIFICATIONS FOR SPHERICAL AND FLETTNER ROTOR MUNITIONS

1. Applicable to sphere and Flettner rotor:

(a) Mean burst height: 10ft, with 85 percent of rounds bursting between 5 and 15 ft, and balance of operable rounds between 0 and 25 ft.

(b) Storage temperature: -40°C to +50°C (interim)
-55°C to +50°C (ultimate)

(c) Operating temperature: +5°C (ideal)
0°C to +55°C limits.

(d) Release conditions: 2,000 to 60,000 ft at speeds subsonic to Mach 4.

(e) Protrusions: None without permission. Air-arming props, vanes and spinners prohibited.

(f) MIL-STD Tests: Fuze must pass applicable jolt, jumble, vibration and 40-ft-drop tests.

2. <u>Applicable only to spherical munition:</u>

(a) Munition weight: 1 7/8 lb, 2/3 of which is payload (550 ml).

(b) Glide angle: 45° to 75° from horizontal.

(c) Coverage: 30 to 40 square miles.

(d) Release: Above 40,000 ft at Mach 0.95 or greater.

(e) Ground approach velocity: 120 to 200 fps along glide path.

(f) Spin rate: 10,000 rpm (max), soon after release, falling to 3000 to 6000 rpm at target.

(g) Cluster: Twenty-seven rounds per package. Aircraft may release total of 1944 spheres for 30-to-40-sq-mi coverage.

(h) Time of fall: 5 to 8 min.

(i) Arming: Fuze shall not arm below 2400-rpm spin rate.

(j) Maximum Fuze Volume: 5 cu in. (interim)
3 cu in. (ultimate), with max length of 4 in. and max diameter of 1.5 in.

(k) Present munition case: Tenite II (cellulose acetate butarate) Wall thickness of 3/32 in. with 1/8-in. flutes.

(l) Development schedule: Prototype phase (tentative design established and feasibility demonstrated) completed by Mid-1958.
Development phase (all OCM requirements met) completed by Mid-1959.

3. Applicable to Flettner-rotor munition only:

(a) Munition weight: 2 to 2 1/2 lb.

(b) Glide angle: 25° to 65° from horizontal.

(c) Ground approach velocity: 50 to 150 fps along glide path.

(d) Spin rate: 10,000 rpm (max) soon after release, falling to 3000 to 4000 rpm.

(e) Time of fall 5 to 10 min.

(f) Arming: Fuze shall not arm below 2500 rpm spin rate.

(g) Maximum Fuse Volume: 5 cu in. (interim)
3 cu in. (ultimate), with
max length of 6 in. and max
diameter of 1 in.

(h) Development Schedule: Prototype phase shall lag that of
spherical round by 6 months. Development
phase completed by Mid-1959.

APPENDIX B

DIELECTRIC PROPERTIES OF PAYLOAD

Measurements were made of both the dielectric constants (K) and the loss tangents (Tan δ) of the payload material. The corresponding values for the diluent alone were also measured. The results verified the prediction that the diluent is the principal factor in determining the electrical characteristics of the payload. Measurements were also made of distilled water and sea water for comparison. All measurements were made at 200 mc/sec at 23°C. The measurements will not vary appreciably over the frequencies of interest. Accuracy of measurement is about ±15 percent.

Material	K	Tan δ
Gelatine-phosphate diluent (plain)	80	0.57
Gelatine-phosphate diluent (plain) with 116-SM-231	69	0.59
Gelatine-phosphate diluent (phenolated)	73	0.55
Gelatine-phosphate diluent (phenolated) with 112-BG-536	70	0.71
Distilled water	79	0.01
Sea water	78	2.0